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Chromium Availability—Domestic

A Minerals Availability System Appraisal

By Jim F. Lemons, Jr., Edward H. Boyle, Jr.,
and Catherine C. Kilgore



UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR

James G. Watt, Secretary

BUREAU OF MINES

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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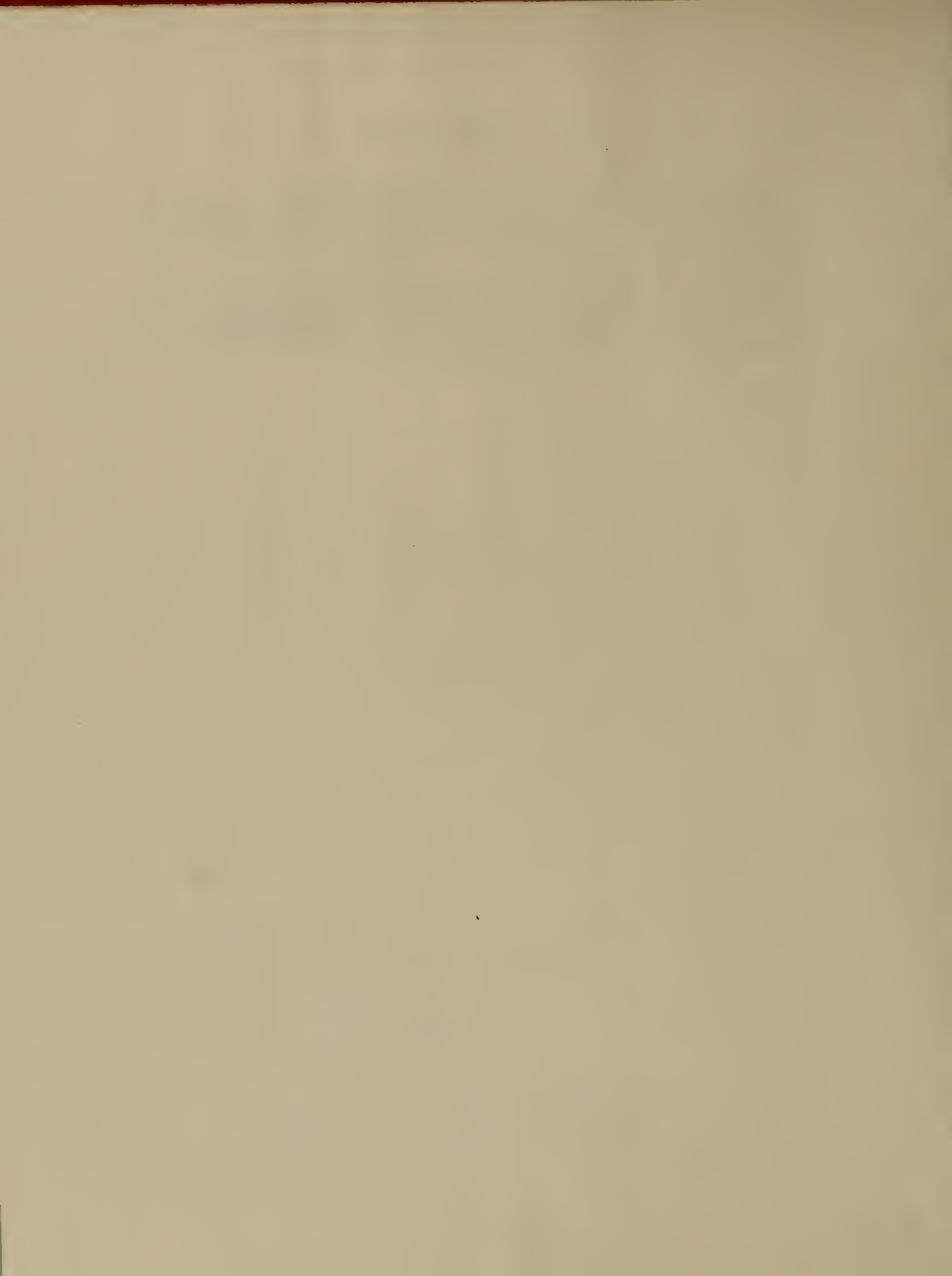
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PREFACE

The purpose of the Bureau of Mines Minerals Availability Program is to assess the worldwide availability of nonfuel minerals. The program identifies, collects, compiles, and evaluates information on active, developed, and explored mines and deposits, and on mineral processing plants worldwide. Objectives are to classify domestic and foreign resources, to identify by cost evaluation resources that are reserves, and to prepare analyses of mineral availabilities.

This report is part of a continuing series of Minerals Availability System (MAS) reports that analyze the availability of minerals from domestic and foreign sources and the factors that affect availability. Analyses of other minerals are currently in progress. Questions about the MAS program should be addressed to Director, Division of Minerals Availability, Bureau of Mines, 2401 E Street, N.W., Washington, D.C. 20241.



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CHROMIUM AVAILABILITY—DOMESTIC

A Minerals Availability System Appraisal

By Jim F. Lemons, Jr.,¹ Edward H. Boyle, Jr.,² and Catherine C. Kilgore²

ABSTRACT

The Bureau of Mines Minerals Availability System collected and analyzed data for 34 nonlaterite and 9 nickeliferous laterite domestic chromite deposits in order to assess their viability as sources of chromium under present technologic and economic conditions. These 43 deposits, none currently in production, contain approximately 6.3 and 22.3 million metric tons of Cr_2O_3 at the demonstrated and identified resource levels, respectively.

Approximately 4.6 and 15.6 million metric tons of Cr_2O_3 are recoverable at the demonstrated and identified levels, respectively, for the 34 nonlaterite deposits. None of these resources are economically recoverable at January 1981 market prices. Production of metallurgical-grade chromite (market price \$128 to \$144) would require a minimum chromite market price of \$237 per metric ton. Chemical-grade chromite production (market price \$74 to \$85) would require a chromite market price in excess of \$188 per metric ton.

From the 34 nonlaterite deposits, roughly 5.4 and 17.6 million metric tons of ferrochrome could be produced at the demonstrated and identified resource levels, respectively; however, a minimum market price of \$770 per metric ton of ferrochrome would be required to stimulate production.

The nine nickeliferous laterite deposits were not evaluated through production stages because of uncertainties in process technology and cost.

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INTRODUCTION

Although chromium is essential for producing stainless steel superalloys and industrial hard plating, and also has a wide range of usage in other alloy steels, pigments, and plating, the United States is almost entirely dependent upon imported sources for its chromium. Production from domestic sources has been sporadic, occurring during periods of high prices or price support, primarily during national emergencies. The last production occurred in 1962. During periods in which international trade is not restrained, production from primary domestic sources has not been economically competitive with foreign sources.

Apparent annual domestic consumption of chromium approximates 500,000 metric tons. Net import reliance is reported to be 90 percent, with the remaining 10 percent satisfied by recycled chromium (13).³ The critical nature of chromium, combined with this high degree of foreign dependence, indicates the need for reliable information on possible sources of domestic supply. Accordingly, this study of the availability of chromium from domestic sources was developed by the Bureau of Mines, Minerals Availability System (MAS), with the intention that this information can contribute to the formation of minerals policy.

The following procedure was used in conducting the study:

1. The quantity and quality (grade, iron content, etc.) of domestic chromite resources were evaluated in relation to physical, technological, institutional, and other conditions that affect production from each deposit.

2. The capital investments and operating costs for appropriate mining, concentrating, and processing methods were estimated.

3. An economic evaluation was performed on each deposit. The results of these analyses indicated the unit prices and associated tonnages of contained chromic oxide (Cr_2O_3) and ferrochromium that could be recovered at specified production levels for each deposit.

4. Price-production relationships were combined and analyzed as contained Cr_2O_3 and ferrochromium availability curves to show the domestic chromium production potential at various commodity prices.

Results of this study are reported in terms of recoverable Cr_2O_3 and ferrochromium at demonstrated and identified resource levels, as these levels are defined in the mineral resource-reserve classification system developed jointly by the Bureau of Mines and the U.S. Geological Survey (14). The demonstrated resource category includes measured and indicated tonnages, and the identified resource category includes inferred as well as demonstrated tonnages (fig. 1). These definitions indicate a greater degree of credibility in the results at the demonstrated resource level. Not all of the deposits that have identified resources will have demonstrated resources, because the classification is dependent upon available geologic and mineralogic data. As additional data become available, deposit resources could be reclassified.

For comparison with current market requirements, the Cr_2O_3 concentrate grade and the chromium-to-iron (Cr:Fe) ratio are also identified. Curves indicate both total and annual potential resource availability for recoverable Cr_2O_3 and ferrochromium.

ACKNOWLEDGMENTS

The authors wish to thank Larry J. Alverson, formerly with the Bureau of Mines, Division of Nonferrous Metals, for his

assistance in establishing the resource tonnages and grades included in this report. Personnel at Bureau of Mines Field Operations Centers in Pittsburgh, Pa., Spokane, Wash., Denver, Colo., and Juneau, Alaska, supplied production and cost data for the deposits included in this study.

³ Italicized numbers in parentheses refer to items in the bibliography preceding the appendices.

Cumulative Production	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range (or)	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserve		Inferred	+	
MARGINALLY ECONOMIC			Reserve		
	Base		Base	+	
SUB- ECONOMIC					
Other Occurrences	Includes nonconventional and low-grade materials				

Figure 1.—Classification of mineral resources.

ESTIMATING CHROMIUM RESOURCE AND COST DATA

The flow of the MAS evaluation process from deposit identification to development of availability curves is illustrated in figure 2. This flowsheet shows the various evaluation stages used in this study to assess the quantity and economics of the chromium available from a property.

Of the 43 domestic deposits investigated (none currently in production), 34 were selected for analysis in this study. Deposits that could share common mills were combined for analysis, resulting in 16 separate evaluations. The nickeliferous laterites were not analyzed in terms of potential production because of technological and cost uncertainties.

Selection of the deposits for this study was limited to known deposits that have significant demonstrated or identified reserves or resources. Resources are concentrations of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust in such form that extraction of a mineral commodity is currently or potentially feasible. Reserves are resources that can be mined, processed, and marketed at a profit under the economic and technologic conditions prevailing at the time of the evaluation.

Most reserve and resource tonnage and grade calculations presented here were computed partly from specific measurements, samples, or production data, and partly from estimations based on geologic evidence.

After all deposits were identified for analysis by the Bureau of Mines Division of Minerals Availability, evaluations of these properties were performed at the Bureau's Field Operations Centers. Data on average grades, ore tonnages, and different physical characteristics affecting production from domestic chromite deposits were obtained from numerous sources, including Bureau of Mines and Geological Survey publications, professional journals, State and industry publications, annual reports, company 10K reports filed with the U.S. Securities and Exchange Commission, data made available to the Bureau of Mines by private companies, and estimates made by Bureau personnel based on personal knowledge and judgments.

The next step entailed an examination of the physical characteristics of each deposit in order to establish a development plan for each property that would yield a

marketable product. Development requirements and production capacities were based on current mining engineering and metallurgical principles. Capital requirements were calculated for exploration, acquisition, development, mine plant and equipment, and constructing and equipping the mill plant. Capital expenditures for the different mining and processing facilities include the costs of mobile and stationary equipment, construction, engineering, facilities and utilities, and working capital. The broad category—facilities and utilities (i.e., infrastructure)—includes, among other things, the cost of the water system, fire protection, roads, fences, and fuel and power distribution. Working capital is a revolving cash fund required for operating expenses such as labor, supplies, taxes, and insurance.

Mine and mill operating costs were also calculated for each deposit. The total operating cost is a combination of direct and indirect costs; direct operating costs include materials, utilities, direct and maintenance labor, and payroll overhead, while indirect operating costs include technical and clerical labor, administrative costs, facilities maintenance and supplies, and research. Other costs in the analysis are fixed charges such as local taxes, insurance, depreciation, deferred expenses, interest payments (if applicable), and return on investment.

When possible, actual company cost data were used. If these were not available, the required capital and operating costs were estimated by standardized costing techniques or through the use of a Cost Estimating System (CES) that was developed for the Bureau of Mines (4). This costing system was designed for preparing capital and operating cost estimates through the use of equations, curves, and factors. The system, based on an average of the costs for existing mining operations in the United States and Canada, covers operations of various sizes. Correct use of the costing system will produce reliable estimates, which historically have fallen within 25 percent of actual costs.

Both feasibility and consistency in these mineral property evaluations, development plans, and associated costs were confirmed and verified at the Bureau's Minerals Availability Field Office, where these data were subsequently used to

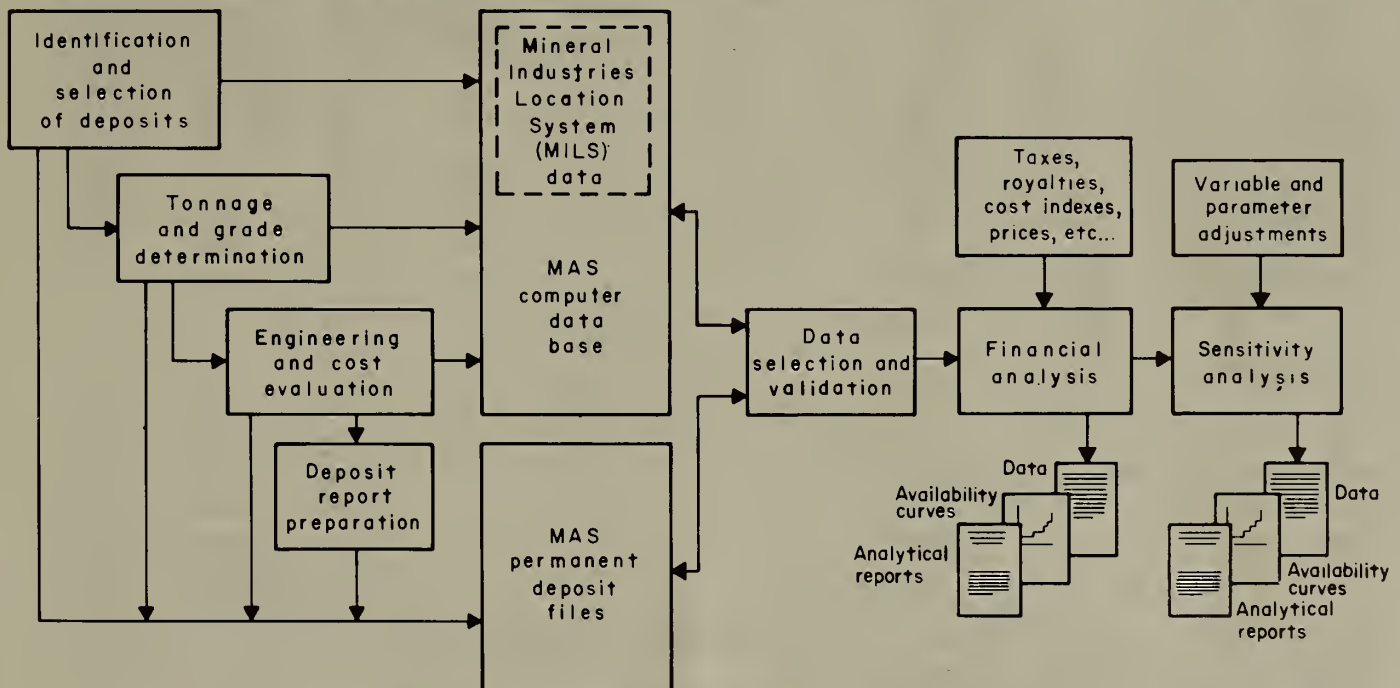


Figure 2.—Flow chart of evaluation procedure.

perform an economic evaluation of each property. This was accomplished through the use of two Bureau-developed computer systems: MINSIM (i.e., MINE SIMulator) for the economic evaluation of individual mineral properties (2), and the Supply Analysis Model (SAM) that is used to evaluate all properties in a defined mineral commodity study area (e.g., domestic chromium) (6). The output of this economic evaluation process is the primary commodity price needed to provide a stipulated rate of return. The rate of return used in this study is the discounted cash flow rate of return

(DCFRROR), most commonly defined as the rate of return that makes the present worth of cash flows from an investment equal to the present worth of all after-tax investments (11, p. 232). For this study, a 15-percent DCFRROR was considered necessary to cover the opportunity cost of capital plus risk.

Individual deposit tonnage price data were then aggregated by the SAM to construct the resource availability curves presented in this study. The study was conducted in constant January 1981 dollars. No escalation of either costs or prices was included.

DOMESTIC CHROMITE DEPOSITS

GENERAL

Tables 1 and 2 show resource information for each of the 43 domestic deposits for which data were collected by the Bureau of Mines. The nine laterite deposits (table 2) have potential for future recovery of chromite; however, an evaluation in terms of cost and price of these deposits was not performed at this time because of technological and cost uncertainties. As noted in tables 1 and 2, the deposits contain 6.3 and 22.3 million tons of contained Cr_2O_3 at the demonstrated and identified resource levels, respectively.⁴ Locations of the chromite deposits are shown on figure 3. Ownership and control data for each property are presented in table A-1 of appendix A.

GEOLOGY

Chromite deposits are formed by primary genesis and secondary reconcentration. Primary genesis occurs by the

crystallization of chromite and other heavy silicates such as olivines and pyroxenes. Secondary chromite deposits are derived from the weathering of chromite-bearing rocks in which the chromite then accumulates either as sedimentary (placer) deposits, or in lateritic soils concentrated in situ by ground water leaching of highly weathered ultramafic rocks.

Chromite of primary genesis origin occurs principally in stratiform and podiform (alpine) deposits. Stratiform deposits, characterized by great lateral extent and uniformity, generally contain low Cr:Fe ratio material. The chromite occurrences of the Stillwater Complex in Montana typify stratiform deposits. Podiform deposits, formed as lenticular or tabular pods, are usually composed of high-chromium or high-aluminum type chromite ore. Deposits of this type include Claim Point and Red Bluff Bay, Alaska, and the Bar Rick and Pilliken Mines in California.

The secondary deposits, derived from reworking and concentrating the primary deposition, are composed of placer and laterite deposits. Principal known placer deposits are the Oregon Beach Sands. Laterite deposits occur in northwestern California and southwestern Oregon.

Before 1940, all domestic production was from podiform

⁴ Tonnage estimates presented in this study are reported in metric tons. To convert from metric tons to short tons, multiply by 1.10231.

Table 1.—Chromite deposit resource information

Property	State	Grade, percent Cr_2O_3	Demonstrated, ¹ thousand metric tons		Identified, thousand metric tons	
			Mineralized material	Contained Cr_2O_3	Mineralized material	Contained Cr_2O_3
Claim Point	Alaska	17.8	267	47.6	267	47.6
Red Bluff Bay	..do.	12.0	30	3.6	30	3.6
Red Mountain	..do.	25.8	0	0	183	47.2
Bar Rick Mine	California	7.6	5,065	384.9	44,512	3,382.9
McGuffy Creek	..do.	W	W	W	W	W
North Elder Creek ²	..do.	11.9	0	0	104	12.4
Pilliken Mine	..do.	5.0	0	0	30,975	1,548.8
Seiad Creek Emma Bell	..do.	5.0	4,546	227.3	10,826	541.3
Louise Chromite	Georgia	.4	131	.6	131	.6
West Placer Area ³	Maryland- Pennsylvania	1.4	729	10.1	729	10.1
Stillwater Complex:						
Mouat Benbow	Montana	W	W	W	W	W
Gish Mine	..do.	15.0	500	75.0	854	128.1
North Carolina Area ²	North Carolina	1.9	108	2.1	178	3.5
Southwest Oregon Beach Sands	Oregon	5.6	10,827	604.1	45,772	2,554.1
Renshaw Placer	Pennsylvania	1.7	209	3.5	209	3.5
Casper Mountain	Wyoming	2.5	3,774	92.5	3,774	92.5
Total ⁴	NAP	NAP	46,604	5,620.6	194,019	19,333.2

NAP Not applicable. W Withheld to avoid disclosing individual company proprietary data; included in total.

¹ Domestic chromite reserve base.

² Includes 3 deposits that have been combined for analysis.

³ Includes 13 deposits that have been combined for analysis.

⁴ Includes resources withheld to avoid disclosing individual company proprietary data.

Table 2.—Chromite-laterite deposit resource information¹

Property	State	Grade, percent Cr ₂ O ₃	Demonstrated, thousand metric tons		Identified, thousand metric tons	
			Mineralized material	Contained Cr ₂ O ₃	Mineralized material	Contained Cr ₂ O ₃
Pine Flat Area:						
Gasquet Laterite	California	W	W	W	W	W
Little Rattlesnake	do	W	W	W	W	W
Lower Elk Camp	do	W	W	W	W	W
Pine Flat Mountain	do	2.8	6,382	178.7	15,052	421.5
Red Mountain	do	W	W	W	W	W
Eight Dollar Mountain						
Red Flat	Oregon	1.1	0	0	13,023	145.9
Rough and Ready	do	W	W	W	W	W
Woodcock	do	1.5	0	0	5,931	90.7
	do	1.3	0	0	8,587	112.5
Total ²	NAp.	NAp	33,813	640.0	143,126	2,995.4

Nap Not applicable. W Withheld to avoid disclosing individual company proprietary data; included in total.

¹ Not included in cost-price analysis because laterite-process technology has not been commercially proven.

² Includes resources withheld to avoid disclosing individual company proprietary data.

deposits, but since then production from the stratiform deposits of the Stillwater Complex has predominated. The majority of the podiform deposits have yielded less than 1,000 tons each and have been economically insignificant.

EXTRACTION METHODS AND COSTS

This study includes deposits that have produced in the past as well as deposits that have no recorded production. Each of these deposits has sufficient resource information so that a mining and beneficiation method can be proposed. The mining and beneficiation methods proposed are based on

those methods used in past domestic production of chromite ores. Thus, recovery of chromite is based on standard placer, open pit, and underground mining methods. The location, deposit type, status, proposed annual capacity, and mining and beneficiation methods for the deposits are shown in table 3. A brief description of the mining method of each deposit is given in appendix B. Many of the deposits are small, particularly those in the Eastern United States, requiring use of highly mobile, small-capacity mining equipment and portable process equipment.

Beneficiation of mined ore is designed to upgrade the Cr₂O₃ content, or increase the Cr:Fe ratio of the chromite; however, most beneficiation of mined ore does not signifi-

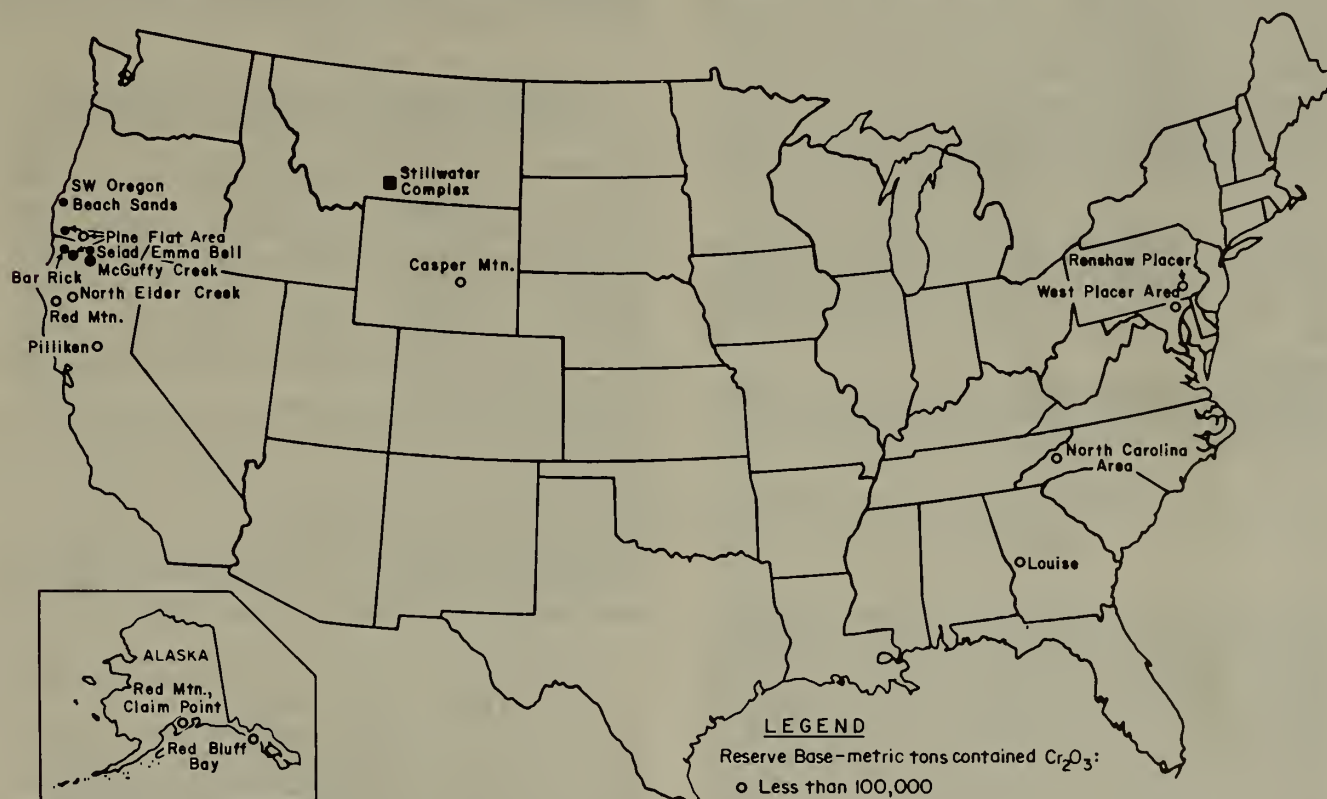
**Figure 3.—Location of domestic chromite properties.**

Table 3.—Chromite deposit status and proposed mining and beneficiation methods

Property	State	Type of deposit	Status ¹	Minimum lead time, years	Annual capacity, metric tons of ore	Mining method	Beneficiation method
Claim Point	Alaska	Podiform	Ppd	4	18,000	Open pit	Gravity
Red Bluff Bay	do	do	Exp	2	9,000	do	Do.
Red Mountain	do	do	Ppd	2	18,000	Overhand shrinkage	Do.
Bar Rick Mine	California	do	Ppd	2	350,000	Sublevel stope	Do.
McGuffy Creek	do	do	Ppd	2	787,500	Open pit	Do.
North Elder Creek ²	do	do	Ppd	1	25,000	do	Do.
Pilliken Mine	do	do	Ppd	2	2,100,000	do	Gravity-magnetic.
Seiad Creek Emma Bell	do	do	Ppd	3	562,500	do	Gravity.
Louise Chromite	Georgia	Placer	Exp	1	25,000	do	Gravity-electrostatic.
West Placer Area ³	Maryland-Pennsylvania	do	Ppd Dev	1	50,000	Placer mining	Do.
Stillwater Complex:							
Mouat Benbow	Montana	Stratiform	Ppd	3	525,000	Shrink stope	Gravity.
Gish Mine	do	do	Dev	2	175,000	do	Do.
North Carolina Area ²	North Carolina	Placer	Ppd Dev	1	25,000	Open pit	Gravity-electrostatic.
Southwest Oregon Beach Sands	Oregon	do	Ppd	2	1,000,000	Strip	Gravity-magnetic-electrostatic.
Renshaw Placer	Pennsylvania	do	Ppd	1	50,000	Open pit	Gravity-electrostatic.
Casper Mountain	Wyoming	Stratiform	Exp	3	377,260	do	Gravity.

¹ Dev—Developing mine; Exp—Explored deposit; Ppd—Past producer.

² Includes 3 deposits combined in the analysis.

³ Includes 13 deposits combined in the analysis.

cantly improve the Cr:Fe ratio, but can increase the total Cr₂O₃ content by separation of gangue. The ore is typically concentrated in a series of gravity-concentrating steps involving tables, spirals, and jigs, with middlings being reground or re-separated. In limited cases, the concentrate can be further upgraded with electrostatic separation; this method will improve the Cr:Fe ratio, but typically works only for high-iron, fine-ground chromites. The current MAS study is based on gravity and electrostatic beneficiation. Chemical separation methods that use flotation or laterite leach-gravity combinations are being investigated at Bureau of Mines research facilities. These methods are discussed in appendix C.

Data in table 4 indicates the range of costs estimated for mining and beneficiating the material of the deposits analyzed in this study. The mining costs have a large variance due to the types and sizes of the operations; there is less variance in the beneficiation costs because the same basic process (gravity separation) is used at all the operations.

Accordingly, a future cost reduction in underground mining and/or gravity separation could have a significant impact on the availability of domestic chromium.

At the demonstrated resource level, roughly 80 percent of the contained Cr₂O₃ would be produced by higher cost, larger underground methods, 8 percent by larger open pit operations, and 11 percent by larger placer operations; less than 1 percent of the chromite production would be attributable to smaller operations.

Table 4.—Estimated costs for mining and beneficiating domestic chromite resources

(January 1981 dollars)

Type of operation	Ore processed per year, metric tons	Typical capital cost per annual metric ton of ore		Operating cost per metric ton of ore ³	
		Mine ¹	Mill ²	Mine	Mill
Small placer	20,000-50,000	\$3-\$4	\$14-\$16	\$2-\$3	\$6-\$10
Large placer	Over 250,000	4- 6	13- 14	1- 2	4- 5
Open pit	Over 250,000	8-22	9- 18	4-11	3- 4
Underground	Over 250,000	21-36	16- 21	16-33	4- 6

¹ Mine capital costs include exploration, development, acquisition, mine equipment, and mine plant.

² Mill capital includes plant and equipment.

³ Operating costs include direct and indirect costs, but do not include depreciation or interest.

AVAILABILITY OF CHROMIUM FROM DOMESTIC DEPOSITS

GENERAL

One function of the MAS program involves performing an engineering cost study to determine the commodity price required to produce a specified level of output from a mineral deposit. Commodity price is defined as the average total cost (ATC) of production from the deposit. Profit, included in the estimate of ATC, is computed at a 15-percent DCFROR. The commodity price can also be defined as the "incentive price" of the deposit, or the price necessary for a firm to be willing to develop the property, including recovery of and return on capital investment (7, pp. 1-25). An illustration of the costing and results of the economic evaluation of a hypothetical chromium operation is included in appendix D.

The quantity of chromium that could be produced and the commodity price required to achieve this production are determined based on the following assumptions:

1. Preproduction for each deposit began in January 1981.
2. Each operation will produce at full operating capacity throughout its life.
3. Competition and demand conditions are such that each operation will be able to sell all of its output at its ATC.
4. The competing market area for the chromium concentrates and ferrochrome is in the Eastern United States.
5. Prices for the chromite concentrates and ferrochrome are CIF (i.e., cost, insurance, and freight paid by the shipper) the marketing area in the Eastern United States.

6. For comparative purposes, the price for chromite concentrates is based upon the Cr_2O_3 content.

7. Current tax structures and 100-percent equity were used in all simulations.

The third assumption implies that the level of demand will support the highest ATC, or that Government subsidies would equal the difference between the market price and the ATC for each submarginal deposit.

The fourth assumption states the basis for the established prices with which domestic chromium production would compete. Two market conditions were analyzed:

1. Chromite concentrates would be transported and sold to existing ferrochromium plants in the Eastern United States.

2. Western chromite concentrates would be processed into a ferrochromium product, with the assumption that ferrochromium plants would be "constructed" at or near the deposits. The ferrochromium product would then be transported to the market in the Eastern United States. The chromite concentrates produced at the deposits in the Eastern United States would be transported to existing ferrochromium plants for further processing.

Time lags involved in filing environmental impact statements, receiving necessary permits, financing, etc., were considered, but were not included in the analysis since it was felt that such delays would be minimized in consideration of strategic availability.

With price and quantity data determined for each deposit, total resource availability curves were constructed for chromium. Total resource curves were constructed for Cr_2O_3 contained in chromite concentrates, and for ferrochromium. The total resource availability curve is not a supply curve in the traditional sense because it ignores the parameter of time, nor is it the industry's marginal cost curve. Rather, the resource availability curve is an aggregate of total production potential from the industry at a stipulated commodity price that covers the full cost of production.

Of primary concern to Government policymakers is not only the question of how much total recoverable chromium exists domestically, but also the amount that could be recovered annually. When performing the engineering analysis of each deposit, Bureau of Mines engineering personnel proposed a development schedule and capacities for each deposit. Such factors as the relative location of the deposit and the necessity for further exploration, development, and plant construction affect the time required to develop each deposit. Also, the depth of overburden, type of mining method employed, and amount of infrastructure required to develop the deposit are significant factors influencing the time lag between initial development and startup.

The annual curves presented in this study are disaggregations of the total resource curves to an annual production basis. These discontinuous functions relate the level of ATC for individual deposits to the cumulative level of production from the deposits over a period of a year. They more closely resemble true supply curves, since they show production on an annual basis, but they also indicate average total cost rather than the marginal cost of production. Constructed annual curves show the Cr_2O_3 in concentrate and the ferrochromium potentially recoverable from domestic deposits.

CHROMITE CONCENTRATE AVAILABILITY

Chromium ores are classified according to their Cr_2O_3 content, the Cr:Fe ratio of the concentrates, and, in the case of refractory-grade ore, the total aluminum plus chromium content. Traditionally, the nonrefractory materials are clas-

sified as high-chrome (metallurgical-grade) and high-iron (chemical-grade) concentrates, as follows:

Percent Cr_2O_3 Cr:Fe ratio

Metallurgical grade . . .	≥ 46	$> 2:1$
Chemical grade	40-46	1.5:1 to 2:1

End use and price of the chrome concentrate is determined by the Cr_2O_3 content and Cr:Fe ratio. Tonnage and price-cost relationships in this study are based on either Cr_2O_3 content of the concentrate, or ferrochromium. The mill concentrate grade, Cr:Fe ratio, and chromite classification for the material derived from the 34 deposits considered in this study are shown in table 5.

Table 5.—Chromite concentrate data

Property	State	Mill concentrate grade, pct Cr_2O_3	Estimated Cr:Fe ratio	Chromite classification ¹
Claim Point	Alaska	45.0	2.7:1	HC
Red Bluff Bay	do	42.0	² 1.6:1	HI
Red Mountain	do	44.0	3:1	HC
Bar Rick Mine	California	44.0	2.4:1	HC
McGuffy Creek	do	41.5	2.5:1	HC
North Elder Creek	do	44.0	3:1	HC
Pilliken Mine	do	44.0	1.5-2.7:1	HC
Seiad Creek/Emma Bell	do	41.5	1.5-2.4:1	HI
Louise Chromite	Georgia	31.0	1.9:1	HI
West Placer Area	Maryland-Pennsylvania	38.7	1.6:1	HI
Stillwater Complex:				
Mouat/Benbow	Montana	42.4	1.7:1	HI
Gish Mine	do	41.2	1.7:1	HI
North Carolina Area	North Carolina	55.0	1.9:1	HI
Southwest Oregon Beach Sands	Oregon	42.0	1.5:1	HI
Renshaw Placer	Pennsylvania	40.0	² 1.6:1	HI ³
Casper Mountain	Wyoming	44.7	2.4:1	HC

¹ Concentrate grade is based on grade categories as specified in Mineral Facts and Problems (12). High-chromium (HC) concentrates have traditionally been used by the metallurgical industry, while high-iron (HI) has traditionally been used by the chemical industry. The HC grades listed here would be marginal; they show a Cr:Fe ratio of greater than 2:1 but a Cr_2O_3 grade greater than or equal to only 44 percent.

² No Cr:Fe ratio was specified, but the grade "chemical" was given. Such specifications were assumed to give a Cr:Fe ratio of 1.6:1.

³ Concentrate from this deposit may be classified as refractory grade. The ore contains more than 20 percent aluminum oxide (Al_2O_3) and more than 60 percent Al_2O_3 plus Cr_2O_3 .

Since the value of the material is based upon quality, prices shown in the tables and illustrations in this study are based on the Cr_2O_3 content of the concentrates. (The concentrates consist of an oxide of iron and chromium— FeCr_2O_4 .) Therefore, to permit a comparison of the cost of potential production from domestic sources to imported material used by the U.S. industry, the chromite prices of the imported material were converted to equivalent Cr_2O_3 content price by dividing the current market prices by the associated Cr_2O_3 grade.

According to current industry information, the pricing structure for chemical-grade material having a Cr:Fe ratio ranging from 1.5:1 to 2.0:1, and a Cr_2O_3 grade ranging from 39 to 46 percent, ranges from \$74 to \$85 per metric ton CIF the marketing area of the Eastern United States. Similarly, the pricing structure for metallurgical-grade material having a Cr:Fe ratio of from 3.0:1 to 3.9:1, and a Cr_2O_3 grade from 46 to 53 percent, ranges from \$128 to \$144 per metric ton CIF the marketing area of the Eastern United States.

For purposes of deriving a price with which domestic production could compete, the price assumed in this study

was \$79 per metric ton CIF the United States for chemical-grade chromite with a 40-percent- Cr_2O_3 content. A price of \$136 per metric ton CIF the United States was used as the competitive price for a metallurgical-grade chromite with a 46-percent- Cr_2O_3 content. These prices, converted to metric tons of contained Cr_2O_3 , are as follows:

	Chromite market price (CIF United States)	Price of contained Cr_2O_3
Chemical-grade, metric ton	\$ 79	\$198
Metallurgical-grade, metric ton	136	296

Total Chromite

Total chromite availability at the demonstrated and identified resource level is shown in figure 4. Metallurgical-grade chromite is shown with dotted lines and chemical-grade chromite with solid lines.

In the analysis, the incentive price and associate tonnage for the identified resource can vary from that for the demonstrated resource. Some properties included in this study have the same tonnage at the demonstrated and identified resource levels (table 1). In these instances, the incentive price remains constant. Other properties have increased tonnage at the identified level, because they have additional inferred tonnage. The incentive price could decrease owing to the additional tonnage, which would increase the life of the operation, thus allowing the capital expenditure to be amortized by additional recoverable units. Some properties have only inferred tonnages, thus increasing the total identified resource. The incentive price would apply to this inferred tonnage.

At the demonstrated resource level, 4.6 million metric tons of Cr_2O_3 in chromite concentrates are potentially recoverable over a production period of 48 years. At the identified resource level, potentially recoverable Cr_2O_3 increases about 240 percent, to 15.6 million metric tons over a production period of 59 years.

Table 6 shows potential recovery of metallurgical- and chemical-grade chromite at various commodity prices. Nearly 90 percent of the resources at the demonstrated level, and over 70 percent at the identified level, would be chemical-grade chromite.

Table 6.—Potential recoverable Cr_2O_3 contained in chromite concentrates at various prices, thousand metric tons

(January 1981 dollars)

Cr_2O_3 price ¹ per metric ton	Demonstrated level		Identified level	
	Chemical	Metallurgical	Chemical	Metallurgical
Less than \$600	3,840	0	10,650	3,850
\$600-\$900	60	400	110	370
\$901-\$1200	190	70	460	120
More than \$1200	20	30	20	30
Total	4,110	500	11,240	4,370

¹ Price based on a metric ton of contained Cr_2O_3 .

At the current market price for chemical-grade chromite, \$198 per metric ton of contained Cr_2O_3 , no domestic chromite is economically available at either the demonstrated or identified resource level. In addition, no metallurgical-grade chromite could be economically produced at the demonstrated level, assuming today's market price of \$296 per metric ton of contained Cr_2O_3 .

Annual Chromite

Based on Cr_2O_3 content, annual domestic consumption of chromite in 1979 was 441,000 metric tons. Consumers were the metallurgical industry (high-chrome chromite)—64 percent, the chemical industry (high-iron chromite)—22 percent,

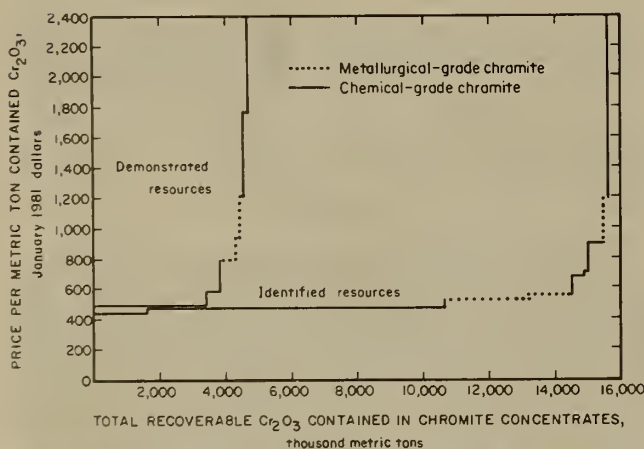


Figure 4.—Chromium total resource availability, 15-percent rate of return.

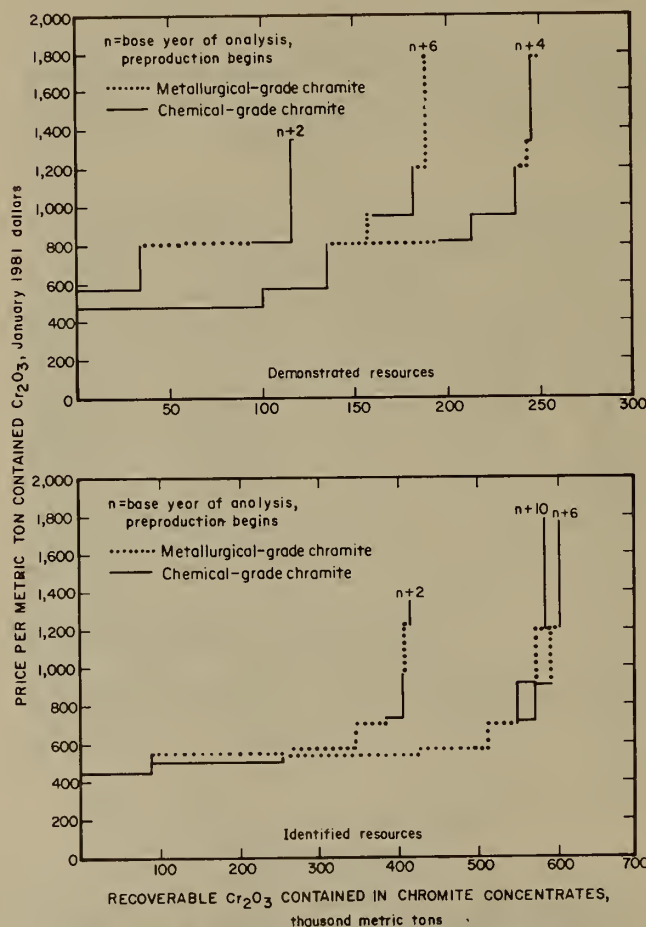


Figure 5.—Chromium annual resource availability, 15-percent rate of return.

and the refractory industry—14 percent. Consumption in 1979 was at the highest level since 1974.

Although no chromite is being produced by U.S. mines, potential annual production (based on Cr_2O_3 content) is shown in figure 5; metallurgical-grade chromite is shown with dotted lines and chemical-grade with solid lines. As shown in the figure, at the demonstrated resource level and at a price of about \$600 per metric ton (significantly above current market price), an estimated 35,000 metric tons could be produced 2 years after preproduction begins. At \$600 per metric ton, production could increase to 140,000 metric tons in year 4, but would begin to decrease shortly thereafter. As mentioned earlier, this decrease reflects the static nature of this study. Future technological developments, the discovery of additional ore bodies, and an increase in commodity price would, with time, reduce the effect of scarcity, and shift the curves to the right.

Potential annual production would increase at the identified resource level because of the addition of properties that are not defined at the demonstrated resource level, and also because of expanded production at operations located on smaller demonstrated reserves. At a \$600 commodity price, nearly 400,000 metric tons could be produced after 2 years.

As shown in figure 5, chromite produced from domestic sources would, in most cases, cost significantly more to produce than that currently being imported. At the demonstrated resource level, possible annual production would be small and of short duration, decreasing after the fourth year. At the identified level, production could be significantly greater and could remain fairly constant for at least 10 years.

FERROCHROMIUM CONCENTRATE AVAILABILITY

Commercial ferrochrome production dates back to the 1860's, when low-grade ferrochrome averaging 7 to 8 percent chromium was produced by direction reduction of chromite and chromiferous iron ores with coke or coal in a blast furnace. By the 1870's, ferrochrome containing 30 to 40 percent chromium was produced by using higher blast furnace temperatures and larger quantities of coke. With the development of the electric arc furnace, however, chromite ore can be processed to high-carbon ferrochromium containing 67 to 71 percent chromium. Chromite and coke are fed into the furnace, the ore is reduced, and the ferrochromium collects at the bottom of the furnace. A high-carbon ferrochromium suitable for low-alloy steels is produced. The product, however, is not suitable for high-chromium steels, such as stainless steel, where low-carbon ferrochromium is needed. Low-carbon ferrochromium is produced by smelting chromites or high-carbon ferrochromium in the presence of silicon.

Development of the argon-oxygen decarburization (AOD) process for making stainless steel made it possible for a lower grade ferrochromium, known as charge chromium, to be marketed. In the AOD process, an adapted converter vessel blows out impurities with a mixture of oxygen and inert argon gas.

Additional processing and transportation charges would be incurred in the production of ferrochromium from chromite. However, because ferrochromium is a refined product, it commands a higher price than chromite. Two ferrochromium products examined in this study are a low-chrome ferrochromium containing 52 percent chrome and a high-chrome ferrochromium containing 65 percent chrome. Over 91 percent of the resources at the demonstrated level and 84 percent at the identified level could be produced to a low-chrome ferrochromium.

Market prices for low-chrome and high-chrome ferrochromium are about the same per pound of contained chromium; however, because of the higher chromium content of high-chrome ferrochromium, the price per metric ton is much greater. Prices as of December 1980 are shown below:

	Cents per pound contained chromium	Dollars per metric ton ferrochromium
Low-chrome ferrochromium (50-55 percent chromium) . . .	45.5-47.5	502-576
High-chrome ferrochromium (60-65 percent chromium) . . .	46.0-52.0	609-745

For this study, the grades selected were 52 and 65 percent for the low-chrome and high-chrome ferrochromium products, respectively. The comparative price of imports CIF the United States, with which the domestic ferrochrome products would compete, are as follows:

Low-chrome ferrochromium (52 percent chromium)	\$522 per metric ton.
High-chrome ferrochromium (65 percent chromium)	\$666 per metric ton.

Recoverable ferrochromium, at both the demonstrated and identified levels, is illustrated in figure 6. The solid lines on the curve indicate low-chrome ferrochromium, and the dotted lines show high-chrome ferrochromium. At a current market price of \$522 per metric ton for low-chrome ferrochromium and \$666 for high-chrome ferrochromium, there are no economically recoverable domestic chromium resources. Recoverable quantities of the low- and high chrome products at various ferrochromium prices are shown on table 7.

Annual potential availability curves for ferrochromium are illustrated in figure 7. High-chrome ferrochromium is shown with dotted lines and low-chrome with solid lines. Most low-chrome ferrochromium is available at a price below \$800 per metric ton, whereas all high-chrome ferrochromium would cost more than \$800.

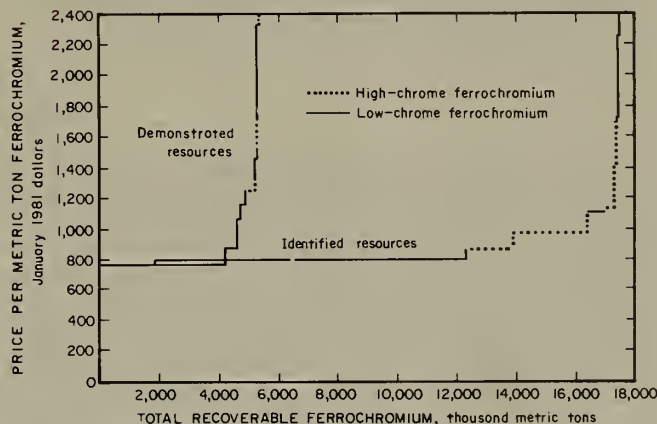


Figure 6.—Ferrochromium total resource availability, 15-percent rate of return.

Table 7.—Potential recoverable ferrochromium at various ferrochromium prices, thousand metric tons

(January 1981 dollars)

Ferrochromium price per metric ton ¹	Demonstrated resources		Identified resources	
	Low- chrome	High- chrome	Low- chrome	High- chrome
Less than \$800 . . .	4,130	0	12,380	0
\$800-\$1200	760	0	680	4,320
More than \$1200 . .	20	480	20	150
Total	4,910	480	13,080	4,470

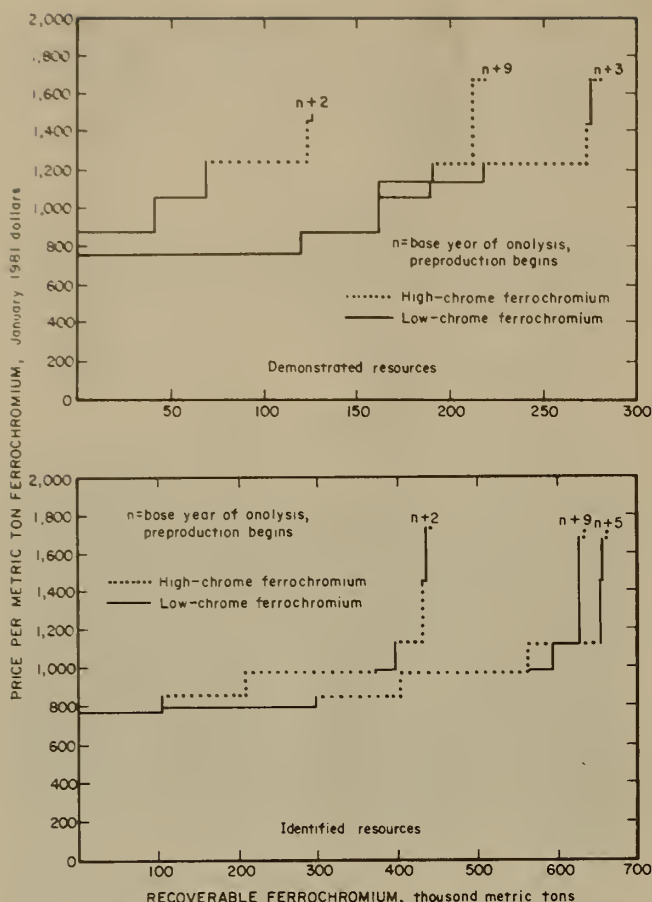


Figure 7.—Ferrochromium annual resource availability, 15-percent rate of return.

CONCLUSIONS

In most instances, metallurgical-grade chromium from domestic deposits would cost significantly more to produce (a minimum market price of \$237 per metric ton of chromite) than the current market price (\$128 to \$144). Chemical-grade chromite production would require a market price in excess of \$188 per metric ton of chromite; the current market price is \$74 to \$85. Based on current known domestic resources, production would be relatively small and of short duration. At the demonstrated resource level, an estimated 4.6 million metric tons of Cr_2O_3 in chromite concentrates could be recovered over a production period of 48 years. Recoverable tonnage increases to 15.6 million metric tons at the identified resource level. Most of the chromite would be

Within the past decade an increasing amount of our chromium imports have been in the form of ferrochrome; our import dependency has shifted from chromium ore to ferrochrome, as chromite-producing countries have built their own ferrochrome plants in an effort to enhance their export revenues. There is understandable concern over the future viability of our domestic ferrochrome industry, since transportation costs favor the production of ferrochrome near the source of the ore; and this concern is intensified by the rising costs of domestic labor, capital, energy, and pollution control. This trend could further reduce our domestic ferrochrome capacity, and could have a significant impact on any future plans for the development of domestic chromium resources.

It should be noted that any substantial increase in the market price of ferrochromium would probably not be met with a corresponding increase in domestic ferrochromium capacity, since the incentive for increasing domestic ferrochromium capacity would probably be restrained by the limited life of domestic chromium production.

suitable for use by the chemical and/or metallurgical industries.

Analyses of the potential availability of the ferrochromium produced from domestic concentrates, and costs of processing, transporting, and producing ferrochromium from chromite concentrate resulted in two products: low-chrome and high-chrome ferrochromium. Over 91 percent of the resources at the demonstrated level and 84 percent at the identified level could be produced to a low-chrome ferrochromium.

At the current market prices for low-chrome (\$522) and high-chrome ferrochromium (\$666), there are no domestic chromium resources that could be economically produced.

BIBLIOGRAPHY

1. Arthur D. Little, Inc. Economic Impact of Environmental Regulations on the United States Copper Industry. Rept. to the U.S. Environmental Protection Agency, January 1978, contract 68-01-2842; available from the American Mining Congress, Washington, D.C.
2. Bennett, H.J., J.G. Thompson, H.J. Quiring, and J.E. Toland. Financial Evaluation of Mineral Deposits Using Sensitivity and Probabilistic Analysis Methods. BuMines IC 8495, 1970, 82 pp.
3. Charles River Associates. Chromite: Market Analysis and Econometric Model. Prepared for U.S. General Services Administration, Cambridge, Mass., June 1973, p. 6.
4. Clement, G.K., Jr., R.L. Miller, P.A. Seibert, L. Avery, and H. Bennett. Capital and Operating Cost Estimating System Manual for Mining and Beneficiation of Metallic and Nonmetallic Minerals Except Fossil Fuels in the United States and Canada. BuMines Special Pub., 1980, 149 pp. Also available as: STRAAM Engineers, Inc. Capital and Operating Cost Estimating System Handbook—Mining and Beneficiation of Metallic and Nonmetallic Minerals Except Fossil Fuels in the United States and Canada. Submitted to the Bureau of Mines under contract JO255026, 1977, 374 pp.
5. Daellenbach, C.B., R.E. Siemes, and D.E. Kirby. Nickel, Cobalt, and Chromium From Domestic Laterites. Sec. in Research 1979. BuMines Special Pub., p. 44.
6. Davidoff, R.L. Supply Analysis Model (SAM): A Minerals Availability System Methodology. BuMines IC 8820, 1979, 45 pp.
7. Dickson, T. Chromite, Southern Africa Holds Sway. Ind. Miner. (London), v. 150, March 1980, p. 56.
8. Harris, D.L. Chemical Upgrading of Stillwater Chromite. Trans. SME/AIME, v. 229, No. 3, September 1964, pp. 267-281.
9. Kusik, C.L., H.V. Makar, and M.R. Mounier. Availability of Critical Scrap Metals Containing Chromium in the United States. Wrought Stainless Steels and Heat-Resisting Alloys. BuMines IC 8822, 1980, 51 pp.
10. National Materials Advisory Board. Contingency Plans for Chromium Utilization. National Academy of Sciences, Washington, D.C., NMAB-335, 1978, p. 347.
11. Stermole F.J. Economic Evaluation and Investment Decision Methods. Investment Evaluations Corp., Golden, Colo., 1974, 443 pp.
12. U.S. Bureau of Mines. Highlights, Aug. 27, 1979, p. 7.
13. _____. Mineral Facts and Problems. Chapter on Chromium, 1976 and 1980.
14. U.S. Geological Survey and U.S. Bureau of Mines. Principles of a Resource/Reserve Classification for Minerals. U.S. Geol. Survey Circ. 831, 1980, 5 pp.

APPENDIX A

Table A-1.—Ownership and control of domestic chromium properties

Property name	Domain	Type of mineral holding	Owner	Percent of ownership
Alaska:				
Claim Point	Federal	Patented	Union Carbide	50
		State lease	Joe Manga	50
Red Bluff Bay	National forest	Minerals only	NA	NA
Red Mountain	State	Patented	R. S. Richards	10
			Union Carbide	84
			Kenai Chrome Co.	6
California:				
Bar Rick Mine	Private	Private lease	Collins H. McClendon	50
			Inspiration Development Co.	50
Gasquet Laterite	National forest	Located claim	California Nickel Corp.	100
Little Rattlesnake	do	do	Del Norte Mining Co.	100
Lower Elk Camp	do	do	California Nickel Corp.	100
McGuffy Creek	do	do	Elmer Weeks	100
North Elder Creek	do	Unknown	California State	100
Pilliken Mine	Private	Patented	Red Line Transfer Co.	100
		Located claim		
Pine Flat Mountain	National forest	do	Hanna Mining Co.	100
Red Mountain	Mixed	do	do	100
		Private lease		
		Fee ownership		
Seiad Creek Emma Bell	National Forest	Located claim	U.S. Chrome	100
		Patented		
Georgia:				
Louise Chromite	Private	Fee ownership	Numerous misc.	100
Maryland:				
Cherry Hill	Private	Fee ownership	H. Pleasant, Jr.	100
Dolfield	do	Unknown	F. A. Dolfield	100
Gore Placer	do	Fee ownership	Paul D. Gore	100
		Private lease		
		State lease		
Lutz Chromite	do	Unknown	A. Lutz	100
Marshall	do	Fee ownership	E. T. Marshall	100
Old Triplett	State	Unknown	NA	NA
Riley Sand	Private	do	H. M. Riley	100
Triplett	State	do	NA	NA
West Placer	Private	do	Mrs. Paul West	100
Montana:				
Benbow Mine	National forest	Patented	Anaconda	100
Gish Mine	do	do	Monte Vista Co.	100
Mouat Mine	do	do	Anaconda	100
North Carolina:				
Holcome	Private	Unknown	NA	NA
Leicester	do	Fee ownership	NA	NA
		Minerals only		
Morgan Hill	do	Unknown	NA	NA
Oregon:				
Eight Dollar Mountain	Mixed	Located claim	Numerous misc.	100
		Private lease		
Red Flat	do	Located claim	Red Flats Nickel	59
			Big Basin Nickel	13
			Hanna Mining Co.	28
			Inspiration Development Co.	95
Rough and Ready	do	do	Walt Freeman	5
		Private lease	NA	NA
Southwest Oregon Beach Sands	Private	Fee ownership		
		Other		
Woodcock	Mixed	Located claim	Hanna Mining Co.	80
			Inspiration Development Co.	15
			California Nickel Corp.	5
Pennsylvania:				
A. T. Reynolds	Private	Unknown	NA	NA
Kirk Sand	do	Fee ownership	Mrs. E. Kirk	100
Slaymaker	do	do	S. R. Slaymaker	100
		Private lease		
		Minerals only		
Renshaw Placer	do	Fee ownership	NA	NA
		Minerals only		
		Private lease		
Wet Pit Slaymaker	do	Unknown	Slaymaker Lock Co.	NA
Wyoming:				
Casper Mountain	Mixed	Patented	Consolidated Mining Co.	NA
		Fee ownership	Wyoming Baptist Convention	NA
			City of Casper	NA

NA Not available.

APPENDIX B.—MINING METHODS

The underground shrinkage-stoping mining method has been proposed for the Mouat, Benbow, and Gish deposits in the Stillwater Complex. Included in the development plan are rehabilitation of old mine workings and development of the main haulage drifts and service shafts at Mouat and Benbow, as well as preproduction development of the stopes and ore passes. At all three properties, the broken ore would be transported underground by rail to a centrally located mill near the portal at the Mouat Mine.

The deposits in Georgia, Maryland, North Carolina, Oregon, and Pennsylvania are small placer and residual deposits that could be surface mined with front-end loaders and trucks, and beneficiated by centrally located or portable concentrating units.

The Bar Rick, McGuffy Creek, North Elder Creek, Pilliken, and Seiad Creek deposits of northern California are past producers of chromite.

Access to the Bar Rick deposit is proposed by driving a main haulage level adit, with the mill near the portal. Preproduction would include driving this level, raising a service and ventilation shaft, and preparing other stope and intermediate levels for the mining that occurs above the main level. Haulage would be by LHD units in the upper workings, and by trolley locomotive on the main level.

The old Emma Bell and Seiad Creek mine workings lie on slopes of ridges above the east and west forks of Seiad Creek. Because the ore zone can be observed in a discontinuous outcrop, open pit mining using front-end loaders and trucks is proposed; little overburden removal or clearing is necessary.

At the Pilliken deposit, over 11 separate ore mineralizations have been identified, and a surface mine operation from three pits has been proposed. Mining would be by power shovels and trucks. Five separate pits are proposed to mine the McGuffy Creek area, utilizing front-end loaders and trucks for both ore and waste removal.

Open pit mining is proposed in the North Elder Creek area. Removing overburden would be necessary, since the deposits are covered by landslide and slope-wash debris.

Three pits are proposed; mining would be by front-end loaders and trucks.

The Red Bluff Bay deposit in Alaska is composed of several mineralized areas. The chromite occurs in small lenses, thin layers, and disseminated grains in ultramafic rocks. Glaciation has removed much of the overburden. Mining from this deposit area would be by front-end loaders and trucks from five open pits.

The Claim Point deposit in Alaska also is composed of numerous individual chromite occurrences. The deposits are near the surface, and open pit mining using front-end loaders and trucks is also proposed for this area.

The Red Mountain, Alaska, deposit is composed of numerous small ore bodies, some of which have produced chromite. The chromite occurs in banded layers within the ultramafic. Proposed is a small underground mining operation using shrinkage stoping, with transportation by rubber-tired transloaders.

Mining the Casper Mountain deposit, Wyoming, would be by open pit methods. The chromite occurs as disseminated grains throughout a schist. Mining of ore and waste rock would include percussion drilling, blasting, front-end loading, and truck hauling. The relatively thin overburden would be removed by self-loading scrapers.

The California-Oregon nickeliferous laterites are of significant lateral extent, limited depth, and low grade. The laterites could be mined by surface methods. The overburden would be ripped and bulldozed, and the lateritic soil extracted by front-end loaders and hauled by trucks to a central screening area. Large boulders would be separated from the weathered soil and discarded. The laterite soil would then be chemically treated to separate cobalt, nickel, and chromite. One of the proposed chemical processes is being developed at the Bureau of Mines Albany (Oreg.) Research Center. To evaluate the Bureau's technology, a pilot plant was recently built to process domestic laterite samples at a rate of 4.5 to 7 metric tons per day. Since this process has not been tested on a commercial scale, the laterite deposit were not included in the availability analysis in this study.

APPENDIX C.—RESEARCH AND DEVELOPMENT

Research has been conducted on chemical concentration of chromite ores; however, no commercial operations have occurred. Processes researched include selective reduction of iron from chromite, partial reduction and acid leaching of iron in a chromium ore, alteration of chromite structure followed by gravity concentration, hydrogen-reduction of chromium from chromium chloride, production of calcium chromite and chromic oxide, and acid decomposition of chromites.

A process that would recover cobalt and nickel from domestic laterites has been investigated at the Bureau of Mines Albany (Oreg.) Research Center. This process entails reducing of oxides in the laterite, ammoniacal-ammonium sulfate leaching, nickel and cobalt solvent extraction, and electrowinning. Chromite in the laterite remains insoluble in the leaching process, and normally reports to tails; however, this residue can be beneficiated to recover chromite concentrates containing an average 27.2-percent- Cr_2O_3 content (leach residue contains only 2.3 percent chromium). The residue would first be fed to a high-shear dispersion mill and separated by screening at 65 mesh and by hydroclone separation. The oversize is discarded, and the undersize is sent to low-intensity magnetic separation where iron oxide is separated and discarded. The nonmagnetic chromites are

then classified and concentrated, principally by tabling. Slime-table middlings are acid scrambled and upgraded with a high-intensity wet-magnetic process. Overall recovery is less than 50 percent of the chromium contained in the leach residue. The concentrate produced is of a lower grade than current chromite concentrates. Studies are being conducted on possible concentrate use.

In 1977, the Bureau of Mines Salt Lake City (Utah) Research Center initiated a study into the beneficiation of low-grade chromite ores from the Stillwater Complex. These studies investigated gravity concentration, flotation, heavy media, and magnetic separation as a means of making an upgraded concentrate suitable for the ferrochrome market. Test results from Albany Research Center indicated that an acceptable grade of ferrochromium can be produced from a gravity concentrate by submerged arc melting. A combined spiral and table-separation technique was successful in upgrading ore from 19 to 41 percent Cr_2O_3 with an overall 92-percent recovery. Magnetic separation of the gravity concentrate, which will increase the Cr:Fe ratio from 1.7 to 1.9, has been more recently investigated in a 100-pound-per-hour process investigation unit, and achieved a 43-percent- Cr_2O_3 concentrate with a recovery of 87 to 91 percent.

APPENDIX D.—COST ANALYSIS OF AN OPEN PIT MINING AND MILLING OPERATION

This appendix contains a brief example of a hypothetical 1,900-metric-ton-per-day open pit mining and milling operation, in order to illustrate the costing and economic evaluation categories used in this study.

For each deposit, an engineering and cost estimate was made to assess the economic feasibility of recovering chromium from that deposit. A mine and mill development plan was proposed based on the reserve or resource, geology, geometry, and mineralogy of the deposit, and standard industry technologies that were applicable. The various components of the development were then costed, including exploration, acquisition, mine preproduction development, mine plant and equipment, mill plant and equipment, mine and mill operating costs, and any proposed infrastructure costs. These costs were based upon proposed equipment lists, scaling costs from similar operations, or by other cost estimating procedures. One such estimating procedure is the Bureau of Mines Cost Estimating System (CES) (10), which enables an engineer to cost an operation based on unit processes and estimated engineering parameters. A summary of the capital cost requirements for a hypothetical chromium property assumed to open pit mine 1,900 metric tons per day of ore and 1,000 metric tons per day of waste, appears in table D-1; the operating costs are illustrated in table D-2.

Table D-1.—Estimated capital requirements for a 1,900-metric-ton-per-day open pit mining and milling operation

	Cost
Mine lease-option cost, property acquisition	\$200,000
Exploration and engineering study	300,000
Preproduction stripping: 11,300,000 tons at \$0.20 per ton	755,000
Mine plant and buildings	834,000
Mine pit equipment	2,167,000
Mill plant and equipment	12,574,000
Working capital	10,773,000
Total capital required	27,603,000

Table D-2.—Estimated operating costs for a 1,900-metric-ton-per-day open pit mining and milling operation

(Dollars per metric ton of ore)

Operation	Labor	Equipment	Material	Total
Surface Mining:				
Production development	\$0.68	\$0.45	\$0.12	\$1.25
Mining of ore	1.70	1.22	.35	3.27
Restoration during production	<.01	<.01	.04	.04
General operations	.31	.02	.06	.39
General administrative expense	.33	.01	.03	.37
Total mining operating costs	3.02	1.70	.60	5.32
Beneficiation:				
Crushing	\$0.31	\$0.17	\$0.07	\$0.55
Grinding	.41	.44	.20	1.05
Concentrating	.78	.08	.34	1.20
Waste and tailings disposal	.12	.02	.06	.20
General (water supply, etc.)	.34	.13	.14	.61
General administrative expense	.47	.01	.04	.52
Total beneficiation operating costs	2.43	.85	.85	4.13

After this cost estimation has been completed, an economic evaluation is made in order to determine the incentive price of chromium necessary to cover these estimated costs, with a desired rate of return on the capital investment. For this example, the 15-percent DCFROR incentive price required to produce ferrochrome concentrate was estimated at \$1,167 per metric ton, in January 1981 dollars. Table D-3 contains data used in the evaluation; table D-4 contains the cumulative financial values derived for the economic evaluation.

Table D-3.—Deposit operating data required for economic evaluation of the 1,900-metric-ton-per-day open pit mining and milling operation

Category description and units	Year of occurrence		Annual category value
	Begin	End	
Exploration	1981	1981	300,000
Land acquisition	1981	1981	200,000
Mining preparation	1981	1982	356,200
Do	1983	1983	42,300
Mine plant	1981	1983	278,100
Mine equipment	1981	1983	722,300
Mill plant and equipment	1981	1983	4,191,300
Working capital	1984	1984	10,773,000
Mine operating cost, per ton ore	1984	1993	5.32
Mill operating cost, per ton ore	1984	1993	4.13
Ore mined per year	1984	1993	570,000
Chromium:			
Feed grade	1984	1993	3.4
Mill recovery	1984	1993	85
Concentrate grade	1984	1993	28.4
Smelter recovery	1984	1993	90
Smelter grade	1984	1993	65
Smelter operating cost, per ton chromite concentrate	1984	1993	170
Transportation to market, per ton ferrochrome	1984	1993	200

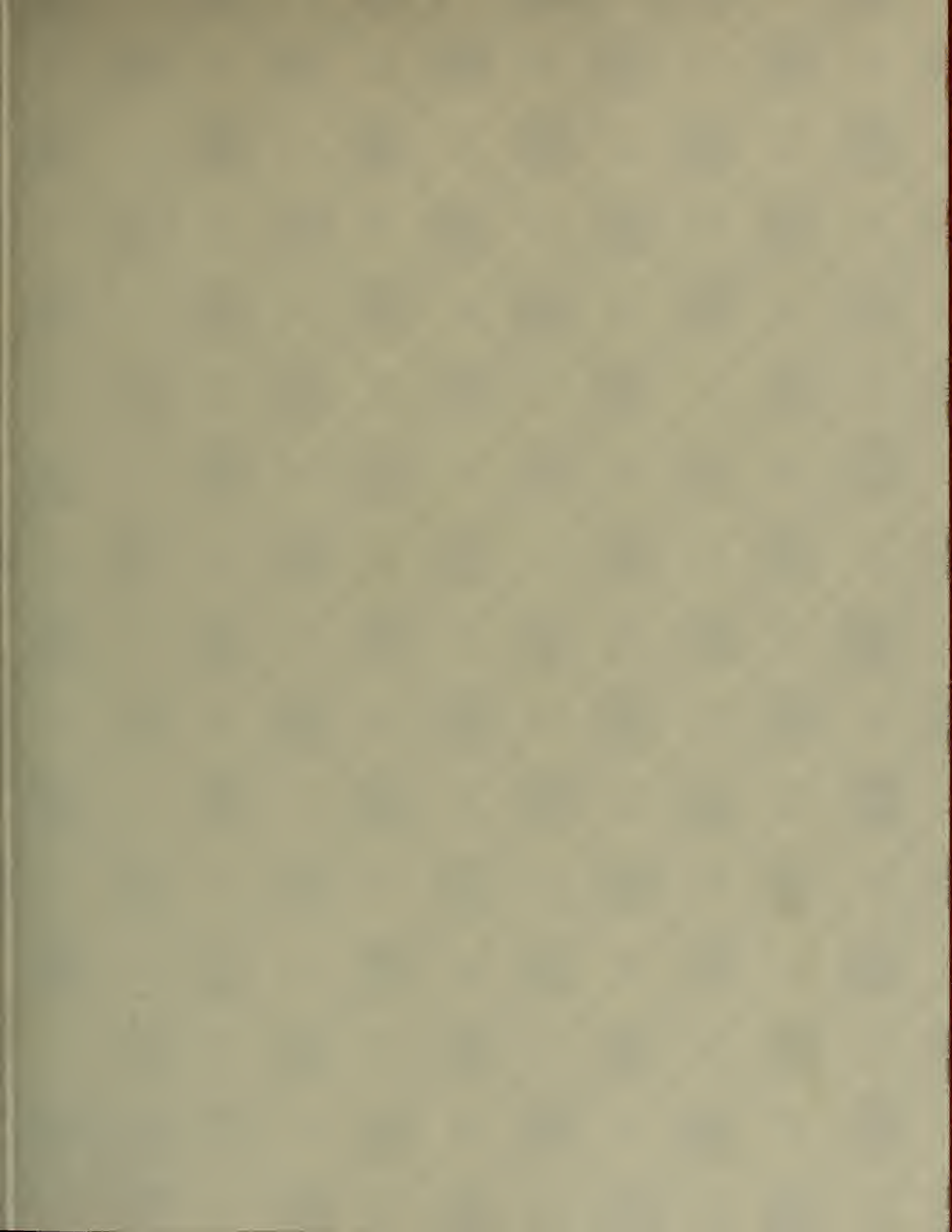
Table D-4.—Cumulative values derived for the economic evaluation of the 1,900-metric-ton-per-day open pit mining and milling operation

	Value
Revenues ¹	\$266,123,000
Royalties	0
Total depreciation	15,575,100
Depletion used	26,254,100
Investment tax credit	1,557,500
Property taxes	798,900
Severance taxes	0
State income taxes	2,218,700
Federal income taxes	11,161,800
Cash flow	37,025,400

¹ The nickel price calculated to produce these revenues at a 15-percent rate of return of and on capital was \$1,166.758 per metric ton of ferrochrome.



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